Preparation of Cheddar Cheese at Elevated Temperatures

ABSTRACT

Reduction of Cheddar cheese making time was investigated by regulating the amount of lactic starter culture initially added to the milk and preparing the cheese at 37.8°C. Laboratory trials showed that in conventional cheese making at 31.1°C, an initial cell count of 10^7 cfu/ml was necessary to achieve a 10^9 cfu/g population density and desirable acidity (pH 5.3 to 5.4) at the milling stage. In the modified process, cheese curd was prepared by prewarming milk to 37.8°C and adding starter culture at 10^8 cfu/ml and milk coagulant (veal rennet) simultaneously. This method shortened preparation time by as much as 90 min, depending on the acid production of the starter culture. Cheeses made in six trials were stored at 4.4°C for 1 yr. Ratings by an expert panel showed no significant differences in flavor, body, and texture characteristics that could be attributed to the method of preparation. On a 5-point intensity scale, increase in sharpness correlated significantly ($P \leq .05$) with storage time with slightly greater increase observed in the experimental cheese. No difference in sharpness was significant between samples made by conventional and experimental methods. Decline in curdiness with storage time showed similar correlations. The results suggested that reduction of make time by increasing starter culture inoculum to 10^8 cfu/ml and renneting at the time of setting at a higher temperature (37.8°C) improved aging characteristics of the finished cheese over the storage time studied.

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INTRODUCTION

The commerical availability of highly concentrated lactic starter cultures allows the regulation of microbial cell density (cfu/ml) in the milk in stages of the cheese making process that precede the cooking of the curd. In the normal Cheddar process, pasteurized milk is usually ripened at 31.1°C with starter culture for 1 h before the addition of rennet (5). During this period the lactic streptococci divide and population density increases accompanied by the production of lactic acid, which, by reducing pH, aids in activation of the milk coagulant (rennet). Highly concentrated starters allow the reduction of make time by eliminating the ripening period. To accomplish this, starter organism is added to the milk in amounts equal the population density expected at the time of cutting of the coagulum.

Peak temperature for cooking the curd in the Cheddar process is normally 37.8°C; higher temperatures may shock the lactic starter organisms, causing a drop in acid production (5). However, inoculation of the milk with starter culture at 37.8°C might reduce the make time further, provided that the acid-producing capacity of the lactic streptococci is not affected.

The purpose of this study was to reduce the make time for Cheddar cheese through elimination of the ripening period by raising milk temperature, increasing initial starter culture concentration to that in the cooking stage of the Cheddar process, and adding milk coagulant (rennet) at the time of setting. Starter culture performance was studied under different conditions and the organoleptic and physical properties of Cheddar cheese produced under modified conditions were evaluated. Portions of the data were reported previously (3, 4).

MATERIALS AND METHODS

Starter Cultures

Multiple strain cultures of lactic streptococci were obtained from commercial sources.

Streptococcus cremoris ATCC 14365, *S. lactis* ATCC 7963 and 11454 were purchased from the American Type Culture Collection (Rockville, MD). Cultures were maintained in 10% (wt/vol) reconstituted nonfat dry milk or Hogg-Jago broth (14) with lactose as the source of carbohydrate. The pH of the media was pH 6.5 before autoclaving. Stock cultures were transferred weekly and incubated at 32°C for 48 h before storage.

Temperature Effect

Laboratory-scale studies of the effects of temperature on the growth and acid production of lactic streptococci and multistrain starter cultures were carried out in 1000-ml portions of pasteurized milk in beakers held in a water bath set at the desired temperature.

Preparation of Cheese

Fresh raw whole milk was obtained from a local dairy during May through August. Milk was cooled to 4.4°C and held overnight before processing. Standard methods were used to determine plate count, total fat, total solids, and titratable acidity in the milk (1, 8, 9).

Milk was heat treated at a temperature of 65.6°C for 16 s in a Chester-Jensen high temperature short time (HTST) plate heat exchanger[3] with a capacity of 3800 L/h and fitted with a Partlow HTST controller with dual diversion point. The heat-treated milk was cooled to the desired temperature and pumped directly to Damrow 760-L, jacketed cheese vats. Samples of heat-treated milk contained less than 10^4 cfu/ml of bacteria before inoculation.

Six independent cheese making trials were carried out in two vats, each holding 746 kg of milk. Starting temperature of the control and experimental vats were 31.1°C (88°F) and 37.8°C (100°F), respectively.

The direct-to-vat concentrated starter cultures had an average cell count of 1.8×10^{11} cfu/ml. At time 0, culture was added to the control to establish a cell count of 1 to 2×10^7 cfu/ml (approximately 30 ml/500 kg of milk), whereas in the experimental vat, initial bacterial count was 1 to 2×10^8 cfu/ml. Both vats were stirred for 5 min to assure even distribution of the starter culture.

Calf rennet was added to the experimental vat at 77 ml/500 kg milk. To the control vat, rennet was added after 1 h ripening at 83.5 ml/500 kg of milk. Average coagulation times were 32 and 25 min for the control and experimental vats, respectively. Curds in each vat were cut horizontally and vertically with .94-cm knives.

The temperature of the control vat was increased to 37.8°C and the curd was cooked for 30 min and then held for 45 min. The curd in the experimental vat was not cooked but held for 1 h after cutting at a setting temperature of 37.8°C.

Both vats were packed, cheddared, and milled in the same manner. Whey was drawn from each vat in 10 min and packing required 5 min. Each type of curd was checked for cell count and acid development 30 min after packing. Control and experimental curds were milled 5 h and 4 h after the start, respectively. Salt was added to each vat at 2.8 kg/500 kg milk. Curds were hooped in 18.2-kg square hoops and held overnight at 3.52 kg/cm^2 pressure in a Damrow cheese press. Cheese blocks were wrapped in Paracote film and cured at 4.4°C for 1 yr.

Analytical Procedures

Bacterial counts during processing and storage were determined by standard procedures (8) except APT agar (Difco) was substituted for plate count agar. The pH was measured at 25°C with a Beckman digital pH meter equipped with a Thomas 4094-L15 combination electrode.

All cheese was analyzed for fat by the Babcock procedure (9). Salt and moisture determinations were according to Association of Official Analytical Chemists (AOAC) procedures (1).

Sensory Procedures

Organoleptic evaluations were carried out in a panel room with light and temperature controlled under the supervision of an experienced panel administrator. Judges consisted

[3] Reference to brand or firm name does not constitute endorsement by the US Department of Agriculture over others of a similar nature not mentioned.

of a group of 14 to 18 laboratory personnel with extensive training in judging commercial Cheddar cheese. The old American Dairy Science Association scoring system (16) was used.[4]

Cheese samples for tasting were withdrawn from storage at 4.4°C after 3, 6 and 12 mo. Cheese blocks were tempered to ambient temperature for 18 h and then sliced into 200 g pieces, which were sealed in plastic bags under vacuum. Randomly coded samples were sliced into uniform portions (5 × 1.25 × 1.25 cm) .5 h before being tasted. A new block of cheese was prepared for each panel.

Samples were also judged for curdiness and sharpness on a 5-point intensity scale (0 to 4) where the higher numbers represented increased sharpness or curdiness.

Panels rated the cheese for preference with the 9-point hedonic scale of Peryam and Pilgrim (11). Our panel size was smaller than that usually employed for this type of panel because of difficulties in assembling enough judges.

Statistical evaluations for significance were made by analysis of variance and Duncan's multiple range test.

RESULTS

The results of laboratory-scale trials indicated that a 37.8°C starting temperature in the make process was not deleterious to either cell viability or acid production of the starter culture. When a direct-to-vat multistrain starter culture was inoculated into milk at 37.8°C at a concentration of 10^7 cfu/ml, it produced acid during incubation, but the live cell count remained almost unchanged (Figure 1). Bacterial count of the same culture in milk held at 31.1°C increased by approximately one order of magnitude and produced acid at a higher rate during the 6-h incubation.

When *S. lactis* ATCC 7963 was inoculated into milk at 37.8°C at a level of 10^8 cfu/ml, it produced acid in similar quantities during the first 3 h of incubation as the culture inoculated at 10^7 cells/ml into milk at 31.1°C (Figure 2). The cell population remained unchanged at

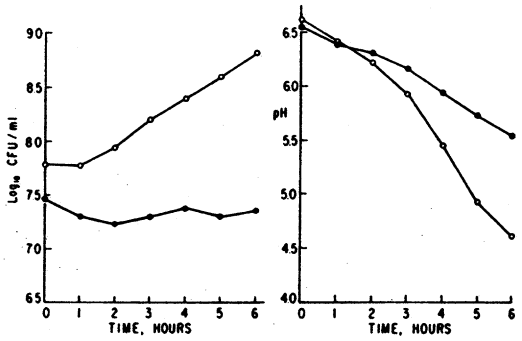

Figure 1. Effect of temperature on growth and acid production of a multistrain starter culture (○, 31.1°C; ●, 37.8°C).

37.8°C, whereas at 31.1°C it increased by one order of magnitude. These results suggested that although growth is either stopped or severely restricted at the higher temperature, the culture can still produce sufficient amounts of acid for cheese making, provided that the initial cell count is adjusted higher.

The increase in cell counts and the pH changes occurring were followed in a conventional cheese making process carried out at 31.1°C with direct set cultures (Figure 3). At the start of ripening, bacterial count was 8 × 10^6 cfu/ml. When the curd was milled 5 h later, the count increased to 1.2 × 10^9 cfu/g. Initially, milk had pH 6.68, whereas curd pH was 5.48 at time of milling.

Other experiments, which were carried out with bulk-set cultures, yielded almost identical results to those obtained with direct-set cultures (data not shown). A 1% inoculum in milk from

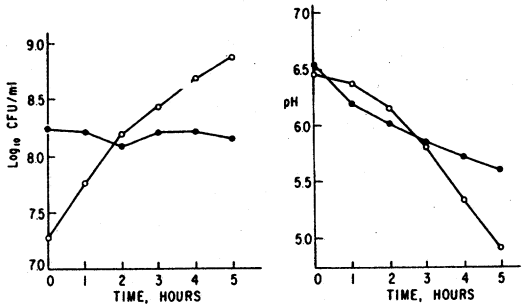

Figure 2. Effect of temperature and initial cell density on growth and acid production of *Streptococcus lactis* ATCC 7963 (○, 31.3°C; ●, 37.8°C).

[4]Work described in this paper was completed before the adoption of the new scoring system.

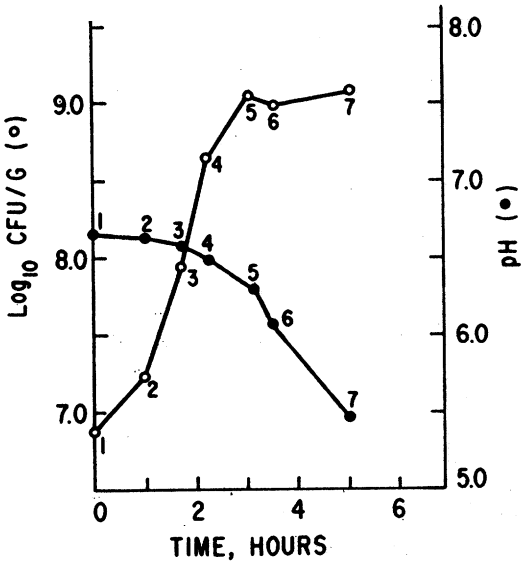

Figure 3. Growth and acid production of direct-set starter culture during conventional large-scale cheese preparation (1, setting; 2, renneting; 3, cutting and t_0 of cooking; 4, holding; 5, packing; 6, 30 min after packing; 7, milling; ○, cfu/g; ●, pH).

a well-developed culture consistently yielded a count of 10^7 cfu/ml. This population density was necessary in either bulk-set or direct-set vats to achieve the desired acid production in the curd at the time of milling.

To determine if a one order of magnitude increase in colony count would eliminate the need for a ripening period, *S. lactis* was inoculated at 10^8 cfu/ml into 1000 ml of milk heated to 37.8°C (Figure 4). The control, which was kept at 31.1°C, received an inoculum of 10^7 cfu/ml.

Rennet was added simultaneously with the starter culture to the experimental milk. Coagulation occurred in 30 min, and although cell count changed little, the pH declined from 6.63 to 6.40. To the control, rennet was added after 1 h of ripening. The control milk coagulated 35 min later and cell count increased to 4.0×10^7 cfu/ml, whereas pH declined from 6.59 to 6.49.

After cutting, the temperature of the control curd was raised to 37.8°C over 30 min and held at cooking temperature for 30 min. During this time, the cell population increased to 7×10^8 cfu/g and pH declined to 6.24. The experimental curd was not cooked but was held at 37.8°C for 60 min after cutting. At the end of the holding period, the cell count was 9.6×10^8 cfu/g and curd pH was 6.14.

After the experimental curd was packed, cell count had increased to 1.5×10^9 cfu/g and curd pH was 5.87. When sampled 30 min later, the cell count remained unchanged but curd pH decreased to 5.84. After the control curd was packed, cell count had increased to 1.5×10^9 cfu/g and pH declined to 5.95.

When the control curd was milled 6.75 h after inoculation, the cell count was 1.7×10^9 cfu/g and curd pH was 5.42. Comparable values were attained in the experimental curd after 4 h 40 min; cell count was 1.9×10^9 cfu/g and curd pH was 5.31. This provided evidence that acid production may be accelerated and the make time shortened by raising the milk temperature and eliminating the ripening period with no deleterious effects on lactic acid development by the starter culture as long as initial cell count was 10^8 cfu/ml.

A study was carried out with *S. cremoris* ATCC 14365 to define the maximum number of bacterial cells that could be added to accelerate acid production and reduce make time without damaging curd quality (Figure 5). Cell growth and acid production were compared at inoculum levels of 10^8 or 10^9 cfu/ml in 1000-ml samples of milk held at 37.8°C and then compared for performance with a culture inoculated at 10^7 cfu/ml into milk held at

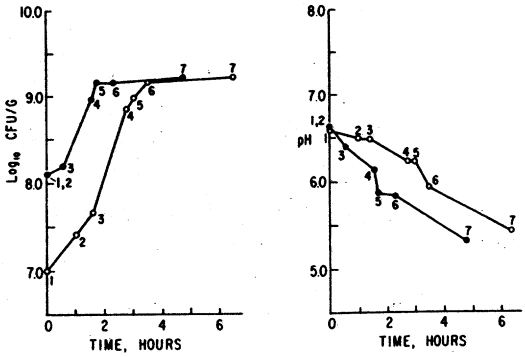

Figure 4. Effect of temperature and initial cell density on growth and acid production of *Streptococcus* lactis ATCC 7963 during small-scale cheese preparation (1, setting; 2, renneting; 3, cutting and t_0 of cooking; 4, holding; 5, packing; 6, 30 min after packing; 7, milling; ○ 31.3°C; ●, 37.8°C).

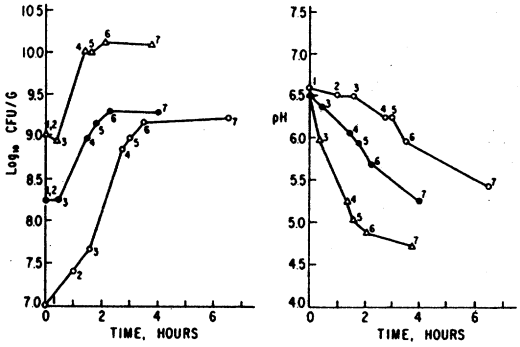

Figure 5. Effect of initial cell density on growth and acid production of *Streptococcus* ATCC 14365 during small-scale cheese preparation at 37.8°C [1, setting; 2, renneting; 3, cutting and t_0 of cooking; 4, holding; 5, packing; 6, 30 min after packing; 7, milling; initial densities were 10^7 (○), 10^8 (●), and 10^9 (Δ) cfu/ml].

31.1°C, as in the normal make process. Growth curves were similar during the make procedure at either 10^7 or 10^8 cfu/ml initial cell density. The apparent increase in cell population in the conventional make process beginning with the end of the cooking period where a temperature of 37.8°C had been attained, to the point 30 min after packing, was approximately equivalent to the apparent growth occurring in the experimental curds during the first 2 h. As shown by the drop in pH in the sample inoculated at 10^9 cfu/ml, acid production was too rapid, resulting in a milling pH of 5.30 by the end of the holding period. Bacterial count increased during this time to 10^{10} cfu/ml, possibly due to shrinkage of the curd after cutting. Cell counts of this level were not encountered during conventional Cheddar cheese making.

Acid production also was accelerated in the curd obtained from milk inoculated with starter culture at 10^8 cfu/ml but curd quality remained comparable with that obtained in the control process. Quality of curds obtained from milk samples inoculated with starter culture at 10^9 cfu/ml and held at 37.8°C was poor. It was concluded that under the experimental conditions used, initial starter culture concentration of higher than 10^9 cfu/ml was not desirable.

Culture performance of *S. cremoris* ATCC 14365 also was tested at 38.9°C (102°F) and compared with 37.8°C (100°F) (Figure 6). Differences in cell count in small trials were minor and acid production was apparently retarded at the higher temperature. Results were similar with *S. lactis* ATCC 11454 and the mixed strain starter MI-1 (Miles Laboratories). Based on these results, the milk temperature was not permitted to exceed 37.8°C under the experimental conditions used. In the pilot plant, average make times in six trials carried out in 760-L vats were reduced by 37% from start to milling, when milk warmed to 37.8°C was set with starter culture at 10^8 cfu/ml (Table 1). Elimination of the ripening period and the apparent aceleration of acid development during the shortened make time did not result in significant changes in pH and cell density between control and experimental curds at time of milling.

Representative analytical data obtained in six independent trials showed insignificant differences in fat, moisture, and salt contents between the control and experimental cheese (Table 2). On a moisture-free basis, the average fat content was 52.7% for experimental cheeses. Yields were calculated from the average of 4476 kg for each set of six trials; the results were 9.1 and 9.3% for the control and experimental cheese, respectively.

After 24 h, pH and cell density of the two types of cheese were similar. Evaluation after 3, 6, and 12 mo of storage at 4.4°C revealed that the experimental cheeses were slightly more acid than the controls. However, all counts were similar and declined at the same rate during storage. Upper limits of the pH (Table

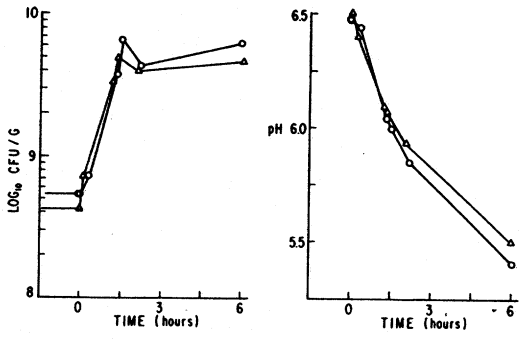

Figure 6. Growth and acid production of *Streptococcus cremoris* ATCC 14365 at 38.9°C during small-scale cheese preparation [1, setting; 2, renneting; 3, cutting and t_0 of cooking; 4, holding; 5, packing; 6, 30 min after packing; 7, milling; ○, 37.8°C process (control); Δ, 38.9°C process].

TABLE 1. Changes in acidity and microbial population during processing of control and experimental cheese.[1]

Step	Control temperature, 31.1°C			Experimental temperature, 37.8°C		
	Time	pH	Bacterial count	Time	pH	Bacterial count
	(min)		(cfu/g)	(min)		(cfu/g)
Culture addition	0	6.64	2.1×10^7	0	6.64	1.3×10^8
Renneting	52	6.61	4.0×10^7	0	6.64	1.3×10^8
Cutting	84	6.59	2.0×10^8	25	6.48	4.8×10^8
Cooking and holding	160	6.38	8.4×10^8	85	6.28	1.2×10^9
Packing	190	6.26	1.6×10^9	115	6.04	2.7×10^9
Packing + 30 min	220	6.01	2.0×10^9	145	5.80	4.0×10^9
Milling	295	5.56	3.8×10^9	186	5.58	3.9×10^9

[1] Average of six trials.

2), which were undesirably high, were consistently found in one sample set of cheese made by the granular Cheddar method (16); pH of samples from the other trials were generally 5.3 or below throughout storage.

To judge the effects of the experimental procedure on the body and texture of the cheese, sensory evaluations were conducted during storage. In the old ADSA scoring system, an overall score between 26 and 30 represents a cheese wth acceptable body and texture. Texture and body of both the control and experimental cheese were rated above 28 points at all of the storage times tested (Table 3).

Range of flavor scores for an acceptable cheese was considered to be 35 to 40 points. The maximum score given a cheese with the old ADSA system is 45; because no cheese can have a perfect flavor, 3 to 5 points are normally deducted (15). Overall scores for the control and experimental cheese showed slight declines over storage with greater decline for control cheese (Table 3). There were only minor differences in score between the control and experiental cheese over storage. Predominant flavors identifiable in both cheese were acid, bitter, and salty.

Both types of cheese had an open but not acid body and thus remained free from crumbling defects on aging. At the end of 1 yr, melting properties of both cheese remained excellent.

Because curdiness significantly influences the body of the finished product, this property was examined closely. Degree of curdiness was rated on a 5-point intensity scale where higher scores indicated greater curdiness. Curdiness declined significantly ($P \leq .05$) in both samples over storage (Table 4). In all cases, experimental cheese showed a greater reduction in curdiness; after 1 yr of storage, experimental cheese was significantly less curdy ($P \leq .05$).

Sharpness is a desirable marketing quality of Cheddar cheese. Cheese was evaluated for this quality during storage, using a 5-point intensity scale of increasing sharpness. Intensity of sharp flavor increased significantly ($P \leq .05$) in both types of cheese over storage (Table 4). Experimental cheese showed somewhat greater development of sharp flavor after 3 and 6 mo of storage at 4.4°C but after 12 mo of storage, there was no apparent difference in the sharpness of the two types of cheese. Score for sharpness intensity was higher than 3 in both cases.

To gain some information about the acceptability of the cheese, the producers were rated on a 9-point hedonic scale (11). After 3 mo of storage, the taste panel preferred the control cheese, but after 6 and or 12 mo of storage, the experimental cheese was rated equally acceptable (Table 4). Hedonic ratings declined for the control and increased for the experimental cheese during storage. Differences were perceived as slight and not significantly different at any time during storage.

DISCUSSION

In the conventional Cheddar cheese making process, heat-treated milk is usually ripened at 31.1°C (88°F) with starter culture (5). During

TABLE 2. Compositional analysis of Cheddar cheese prepared at 31.1°C and 37.8°C; changes in pH and microbial population during storage.[1]

	Control		Experimental	
	Range	Average	Range	Average
Fat, %	33.2–34.0	33.6	32.5–32.8	32.6
Fat in total solids, %	52.0–54.7	53.8	50.1–54.4	52.7
Moisture, %	35.0–38.9	37.6	35.8–40.3	38.2
Salt, %	1.72–2.05	1.84	1.22–2.05	1.76
Yield, %	8.5–9.9	9.1	8.6–10.3	9.3
pH, 24 h	5.23–5.52	5.34	5.16–5.47	5.31
cfu/g, 24 h	$1.1–4.7 \times 10^9$	3.3×10^9	$1.3–4.9 \times 10^9$	3.8×10^9
pH, 3mo	5.10–5.54	5.28	5.07–5.45	5.21
cfu/g, 3 mo	$5 \times 10^8–2.3 \times 10^9$	1.4×10^9	$1.6 \times 10^8–1.2 \times 10^9$	6.0×10^8
pH, 6 mo	5.25–5.57	5.37	5.06–5.46	5.24
cfu/g, 6 mo	$9 \times 10^7–1 \times 10^9$	6.0×10^8	$1 \times 10^7–9 \times 10^8$	2.5×10^8
pH, 12 mo	5.15–5.64	5.29	5.13–5.52	5.24
cfu/g, 12 mo	$9.8 \times 10^4–1 \times 10^8$	2.5×10^7	$1.3 \times 10^5–4.7 \times 10^7$	1.2×10^7

[1] Average of six trials.

this period, the bacterial population increases two- to three-fold and lactic acid is produced, which aids in enzyme activation when rennet is added. During the subsequent cutting, cooking, packing, and milling stages, the number of lactic streptococci increases, and a population of 10^9 (cfu)/g is common in Cheddar cheese. If the cell count is low, insufficient acid will be produced by the time of milling. However, if the cell count is excessive, acid will be produced too rapidly and the cheese will lack the proper moisture content. Our preliminary studies showed that in either bulk-set or direct-set cheese vats, initial count of about 1×10^7 cfu/ml of lactic streptococci was necessary to achieve desired cell density and acid production at time of milling (Figure 1).

Normally the peak temperature for cooling Cheddar cheese curds is 37.8°C. A higher temperature may deleteriously affect the lactic starter organisms (*S. lactis* and *S. cremoris*), retarding acid production and resulting in a "slow vat" (5). It has been suggested that although the growth of certain lactic starter organisms is inhibited at 37.8°C, they can still produce lactic acid in sufficient quantity to allow the cheese making process to proceed normally (7). It was also reported that "bitter" strains of group N streptococci produce acid in the curd more rapidly than "nonbitter" strains (6). The higher rate of acid production and the tendency to yield bitter cheese by the "bitter" strains is presumably the result of excessively high microbial population in the curd. The generally lower cell populations of "nonbitter" strains result from growth inhibition at 37.8°C (7). Because both "bitter" and "nonbitter" strains produce sufficient acid during cheese production to reduce curd pH to the required level, it appeared that inhibition of the growth of "nonbitter" strains at 37.8°C failed to induce a corresponding inhibition of acid synthesis by these organisms. Breheny et al. (2). demonstrated that at temperatures commonly used in Cheddar cheese making, some strains of *S. cremoris* and *S. lactis* were still able to produce acid in milk under conditions that inhibited their growth.

By initially adding the starter culture at concentrations approximately equivalent to those found at the end of the cooking stage of a normal Cheddar cheese operation (10^8 cfu/ml), we demonstrated that although little or no

TABLE 3. Flavor and texture and body characteristics of Cheddar cheese prepared at 31.1°C and 37.8°C.

	Control			Experimental		
	3 mo	6 mo	12 mo	3 mo	6 mo	12 mo
Overall flavor score[1]	38.29	38.35	37.78	38.38	38.23	38.13
Overall texture and body score[2]	28.40	28.39	28.35	28.53	28.43	28.40

[1] Average of six trials were obtained with the American Dairy Science Association (ADSA) scoring system (16) with a maximum score of 40 points.

[2] Average of six trials were obtained with the ADSA scoring system (16) with a maximum score of 30 points.

growth occurred at the elevated temperature, acid production proceeded normally or at a slightly accelerated rate (Figures 4 and 5). Increase in cell density with time in the elevated temperature process probably resulted from curd shrinkage rather than from actual cell division. Similar results were obtained with an initial cell count of 10^9 cfu/ml (Figure 5). The same phenomenon was also found in a normal make procedure (31.1°C) during cutting and cooking stages with cell densities eventually reaching 10^8 to 10^9 cfu/g of curd (Figure 3). When the temperature exceeded 37.8°C, cell count remained relatively unchanged (Figure 6), but because acid synthesis was inhibited, make time became unacceptably long.

Problems with bitter flavor also occur when high populations of proteinase-positive (Prt^+) cells of lactic starter cultures are present at milling (10). Because mixed-strain cultures were used in our studies, a portion of population was expected to be Prt^+. Even though cell density in our experimental cheese was initially higher, we experienced a slightly lower degree of bitterness than in the controls (Table 4) after 3 and 6 mo of storage, providing further evidence that significant growth did not occur in the course of the elevated temperature process.

Mills and Thomas (10) have shown that high quality Cheddar cheese can be made with starter cultures containing high proportions of

TABLE 4. Additional sensory characteristics of Cheddar cheese prepared at 31.1°C and 37.8°C.[1]

Property of cheese	Storage[4]		
	3 mo	6 mo	12 mo
Sharpness[2]			
Control	1.80[a]	2.59[b]	3.24[c]
Experimental	1.97[a]	2.85[b]	3.25[c]
Curdiness[2]			
Control	3.54[a]	2.81[a]	2.19[b]
Experimental	3.29[a]	2.60[a]	1.49[b]
Acceptability[3]			
Control	6.98[a]	6.80[a]	6.55[a]
Experimental	6.00[a]	6.64[a]	6.86[a]

[a,b,c] Numbers with different letters differ significantly ($P \leq .05$).

[1] Average values of six trials.

[2] Rated on a 5-point intensity scale where higher scores represent increased sharpness or curdiness.

[3] Rated on a 9-point hedonic scale according to Peryam and Pilgrim (11).

proteinase-negative (Prt^-) strains, but their exclusive use was not recommended because make times became unacceptably long. Our accelerated make procedure would eliminate this problem, provided that a higher number of Prt^- cells produced a normal amount of acid. Richardson et al. (12) demonstrated that high concentrations of Prt^- variants produce sufficient amounts of acid in milk at 38°C in 5 h to qualify them for use as starter cultures in Cheddar cheese manufacture. The Prt^- cells outperformed Prt^+ cells in acid production at temperature range of 38 to 42°C (13), suggesting that use of Prt^- cells may be feasible in the elevated temperature cheese making process developed in our laboratories. If Prt^- starters were available in 10^{10} to 10^{11} cfu/ml concentrates, then a 1 or .1% inoculum in our modified process would lead to acidity adequate to allow Cheddar cheese making in reduced time. This possibility remains to be investigated.

Some modifications would have to be made in the experimental procedure described here to allow its development into a commerical-scale process. The main advantage of our procedure is the shortened make time, which allows the production of more cheese in a day with no additional capital investment for equipment. In addition, the apparently more rapid acid development observed with the elevated temperature may help to control the growth of undesirable microbes in the early stages of cheese making.

ACKNOWLEDGMENT

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TABLE 1. Changes in acidity and microbial population during processing of control and experimental cheese.[1]

Step	Control temperature, 31.1°C			Experimental temperature, 37.8°C		
	Time	pH	Bacterial count	Time	pH	Bacterial count
	(min)		(cfu/g)	(min)		(cfu/g)
Culture addition	0	6.64	2.1×10^7	0	6.64	1.3×10^8
Renneting	52	6.61	4.0×10^7	0	6.64	1.3×10^8
Cutting	84	6.59	2.0×10^8	25	6.48	4.8×10^8
Cooking and holding	160	6.38	8.4×10^8	85	6.28	1.2×10^9
Packing	190	6.26	1.6×10^9	115	6.04	2.7×10^9
Packing + 30 min	220	6.01	2.0×10^9	145	5.80	4.0×10^9
Milling	295	5.56	3.8×10^9	186	5.58	3.9×10^9

[1] Average of six trials.

2), which were undesirably high, were consistently found in one sample set of cheese made by the granular Cheddar method (16); pH of samples from the other trials were generally 5.3 or below throughout storage.

To judge the effects of the experimental procedure on the body and texture of the cheese, sensory evaluations were conducted during storage. In the old ADSA scoring system, an overall score between 26 and 30 represents a cheese wth acceptable body and texture. Texture and body of both the control and experimental cheese were rated above 28 points at all of the storage times tested (Table 3).

Range of flavor scores for an acceptable cheese was considered to be 35 to 40 points. The maximum score given a cheese with the old ADSA system is 45; because no cheese can have a perfect flavor, 3 to 5 points are normally deducted (15). Overall scores for the control and experimental cheese showed slight declines over storage with greater decline for control cheese (Table 3). There were only minor differences in score between the control and experiental cheese over storage. Predominant flavors identifiable in both cheese were acid, bitter, and salty.

Both types of cheese had an open but not acid body and thus remained free from crumbling defects on aging. At the end of 1 yr, melting properties of both cheese remained excellent.

Because curdiness significantly influences the body of the finished product, this property was examined closely. Degree of curdiness was rated on a 5-point intensity scale where higher scores indicated greater curdiness. Curdiness declined significantly ($P \leq .05$) in both samples over storage (Table 4). In all cases, experimental cheese showed a greater reduction in curdiness; after 1 yr of storage, experimental cheese was significantly less curdy ($P \leq .05$).

Sharpness is a desirable marketing quality of Cheddar cheese. Cheese was evaluated for this quality during storage, using a 5-point intensity scale of increasing sharpness. Intensity of sharp flavor increased significantly ($P \leq .05$) in both types of cheese over storage (Table 4). Experimental cheese showed somewhat greater development of sharp flavor after 3 and 6 mo of storage at 4.4°C but after 12 mo of storage, there was no apparent difference in the sharpness of the two types of cheese. Score for sharpness intensity was higher than 3 in both cases.

To gain some information about the acceptability of the cheese, the producers were rated on a 9-point hedonic scale (11). After 3 mo of storage, the taste panel preferred the control cheese, but after 6 and or 12 mo of storage, the experimental cheese was rated equally acceptable (Table 4). Hedonic ratings declined for the control and increased for the experimental cheese during storage. Differences were perceived as slight and not significantly different at any time during storage.

DISCUSSION

In the conventional Cheddar cheese making process, heat-treated milk is usually ripened at 31.1°C (88°F) with starter culture (5). During

TABLE 2. Compositional analysis of Cheddar cheese prepared at 31.1°C and 37.8°C; changes in pH and microbial population during storage.[1]

	Control		Experimental	
	Range	Average	Range	Average
Fat, %	33.2–34.0	33.6	32.5–32.8	32.6
Fat in total solids, %	52.0–54.7	53.8	50.1–54.4	52.7
Moisture, %	35.0–38.9	37.6	35.8–40.3	38.2
Salt, %	1.72–2.05	1.84	1.22–2.05	1.76
Yield, %	8.5–9.9	9.1	8.6–10.3	9.3
pH, 24 h	5.23–5.52	5.34	5.16–5.47	5.31
cfu/g, 24 h	$1.1–4.7 \times 10^9$	3.3×10^9	$1.3–4.9 \times 10^9$	3.8×10^9
pH, 3mo	5.10–5.54	5.28	5.07–5.45	5.21
cfu/g, 3 mo	$5 \times 10^8–2.3 \times 10^9$	1.4×10^9	$1.6 \times 10^8–1.2 \times 10^9$	6.0×10^8
pH, 6 mo	5.25–5.57	5.37	5.06–5.46	5.24
cfu/g, 6 mo	$9 \times 10^7–1 \times 10^9$	6.0×10^8	$1 \times 10^7–9 \times 10^8$	2.5×10^8
pH, 12 mo	5.15–5.64	5.29	5.13–5.52	5.24
cfu/g, 12 mo	$9.8 \times 10^4–1 \times 10^8$	2.5×10^7	$1.3 \times 10^5–4.7 \times 10^7$	1.2×10^7

[1] Average of six trials.

this period, the bacterial population increases two- to three-fold and lactic acid is produced, which aids in enzyme activation when rennet is added. During the subsequent cutting, cooking, packing, and milling stages, the number of lactic streptococci increases, and a population of 10^9 (cfu)/g is common in Cheddar cheese. If the cell count is low, insufficient acid will be produced by the time of milling. However, if the cell count is excessive, acid will be produced too rapidly and the cheese will lack the proper moisture content. Our preliminary studies showed that in either bulk-set or direct-set cheese vats, initial count of about 1×10^7 cfu/ml of lactic streptococci was necessary to achieve desired cell density and acid production at time of milling (Figure 1).

Normally the peak temperature for cooling Cheddar cheese curds is 37.8°C. A higher temperature may deleteriously affect the lactic starter organisms (*S. lactis* and *S. cremoris*), retarding acid production and resulting in a "slow vat" (5). It has been suggested that although the growth of certain lactic starter organisms is inhibited at 37.8°C, they can still produce lactic acid in sufficient quantity to allow the cheese making process to proceed normally (7). It was also reported that "bitter" strains of group N streptococci produce acid in the curd more rapidly than "nonbitter" strains (6). The higher rate of acid production and the tendency to yield bitter cheese by the "bitter" strains is presumably the result of excessively high microbial population in the curd. The generally lower cell populations of "nonbitter" strains result from growth inhibition at 37.8°C (7). Because both "bitter" and "nonbitter" strains produce sufficient acid during cheese production to reduce curd pH to the required level, it appeared that inhibition of the growth of "nonbitter" strains at 37.8°C failed to induce a corresponding inhibition of acid synthesis by these organisms. Breheny et al. (2). demonstrated that at temperatures commonly used in Cheddar cheese making, some strains of *S. cremoris* and *S. lactis* were still able to produce acid in milk under conditions that inhibited their growth.

By initially adding the starter culture at concentrations approximately equivalent to those found at the end of the cooking stage of a normal Cheddar cheese operation (10^8 cfu/ml), we demonstrated that although little or no

TABLE 3. Flavor and texture and body characteristics of Cheddar cheese prepared at 31.1°C and 37.8°C.

	Control			Experimental		
	3 mo	6 mo	12 mo	3 mo	6 mo	12 mo
Overall flavor score[1]	38.29	38.35	37.78	38.38	38.23	38.13
Overall texture and body score[2]	28.40	28.39	28.35	28.53	28.43	28.40

[1] Average of six trials were obtained with the American Dairy Science Association (ADSA) scoring system (16) with a maximum score of 40 points.

[2] Average of six trials were obtained with the ADSA scoring system (16) with a maximum score of 30 points.

growth occurred at the elevated temperature, acid production proceeded normally or at a slightly accelerated rate (Figures 4 and 5). Increase in cell density with time in the elevated temperature process probably resulted from curd shrinkage rather than from actual cell division. Similar results were obtained with an initial cell count of 10^9 cfu/ml (Figure 5). The same phenomenon was also found in a normal make procedure (31.1°C) during cutting and cooking stages with cell densities eventually reaching 10^8 to 10^9 cfu/g of curd (Figure 3). When the temperature exceeded 37.8°C, cell count remained relatively unchanged (Figure 6), but because acid synthesis was inhibited, make time became unacceptably long.

Problems with bitter flavor also occur when high populations of proteinase-positive (Prt^+) cells of lactic starter cultures are present at milling (10). Because mixed-strain cultures were used in our studies, a portion of population was expected to be Prt^+. Even though cell density in our experimental cheese was initially higher, we experienced a slightly lower degree of bitterness than in the controls (Table 4) after 3 and 6 mo of storage, providing further evidence that significant growth did not occur in the course of the elevated temperature process.

Mills and Thomas (10) have shown that high quality Cheddar cheese can be made with starter cultures containing high proportions of

TABLE 4. Additional sensory characteristics of Cheddar cheese prepared at 31.1°C and 37.8°C.[1]

Property of cheese	Storage[4]		
	3 mo	6 mo	12 mo
Sharpness[2]			
Control	1.80[a]	2.59[b]	3.24[c]
Experimental	1.97[a]	2.85[b]	3.25[c]
Curdiness[2]			
Control	3.54[a]	2.81[a]	2.19[b]
Experimental	3.29[a]	2.60[a]	1.49[b]
Acceptability[3]			
Control	6.98[a]	6.80[a]	6.55[a]
Experimental	6.00[a]	6.64[a]	6.86[a]

[a,b,c] Numbers with different letters differ significantly ($P \leq .05$).

[1] Average values of six trials.

[2] Rated on a 5-point intensity scale where higher scores represent increased sharpness or curdiness.

[3] Rated on a 9-point hedonic scale according to Peryam and Pilgrim (11).

proteinase-negative (Prt^-) strains, but their exclusive use was not recommended because make times became unacceptably long. Our accelerated make procedure would eliminate this problem, provided that a higher number of Prt^- cells produced a normal amount of acid. Richardson et al. (12) demonstrated that high concentrations of Prt^- variants produce sufficient amounts of acid in milk at 38°C in 5 h to qualify them for use as starter cultures in Cheddar cheese manufacture. The Prt^- cells outperformed Prt^+ cells in acid production at temperature range of 38 to 42°C (13), suggesting that use of Prt^- cells may be feasible in the elevated temperature cheese making process developed in our laboratories. If Prt^- starters were available in 10^{10} to 10^{11} cfu/ml concentrates, then a 1 or .1% inoculum in our modified process would lead to acidity adequate to allow Cheddar cheese making in reduced time. This possibility remains to be investigated.

Some modifications would have to be made in the experimental procedure described here to allow its development into a commerical-scale process. The main advantage of our procedure is the shortened make time, which allows the production of more cheese in a day with no additional capital investment for equipment. In addition, the apparently more rapid acid development observed with the elevated temperature may help to control the growth of undesirable microbes in the early stages of cheese making.

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